Rb-Sr and U-Pb age patterns in polymetamorphic sediments from the southern part of the East Greenland Caledonides

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Rb-Sr analyses on sediments once believed to be late Precambrian show evidence of a middle Proterozoic metamorphic event overprinted by a Caledonian event which only partly reset the isotopic systems. U-Pb analyses on monazites support the Rb-Sr data, whereas zircons show evidence of a detrital origin from an older source region. The age patterns support speculation of the presence of widespread early Proterozoic deposition and a signifiiant middle Proterozoic orogenic episode within the East Greenland Caledonides.

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The Caledonian fold belt in East Greenland is dominated by metampophic complexes, bordered to the east and partially overlain by thick sequences of weakly folded late Precambrian and Lower Palaeozoic sediments. The metamorphic complexes comprise extensive infracrustal bodies of gneisses, granitic rocks and migmatites enveloped and folded together with high grade metasedimentary rocks (fig. 1). Some early workers (e.g. Parkinson & Whittard 1931; Teichert 1933; Odell 1944) had considered the infracrustal bodies to be Archean massifs. Later workers claimed to be able to trace the stratigraphy of the late Precambrian Eleonore Bay Group into the high grade metasediments and also throughout the gneisses and migmatites, and therefore regarded the metamorphic complexes as a product of Caledonian granitization and migmatization; the infracrustal bodies were viewed as sheets and masses of mobile Caledonian elements emplaced into and transforming the metasediments which were supposed to represent parts of the late Precambrian succession. The concept of a deep seated Caledonian orogeny is most comprehensively presented by Haller (1971).

Systematic mapping in the Scoresby Sund region (70°–72°N) by the Geological Survey of Greenland (GGU) in the period 1968–72 at first appeared to confirm the traditional view of one intense Caledonian orogenesis. However, isotopic studies have revealed a complex pre-Caledonian history.

Geology of the Scoresby Sund region (70°–72°N)

Crystalline rocks crop out in the western half of the Scoresby Sund region and in the narrow strip of Liverpool Land in the extreme east (fig. 1). The two areas are separated by a broad zone of post-Caledonian rocks, principally Mesozoic sediments. The western broad area of crystalline rocks is divided into several distinctive N–S trending zones by major thrusts.

In the extreme west, thrusts on which westward displacements may exceed 40 km outline tectonic windows in the Paul Stern Land and Charcot Land areas and expose parts of the Greenland shield, representing the foreland of the Caledonian fold belt. The foreland windows are bordered to the east by a zone 40–60 km wide, traceable from western Gåseland northwards to Hinks Land, and bounded on both sides by eastward dipping thrusts; this zone comprises two main lithostratigraphic units, the Flyverfjord infracrustal complex and the Krummedal supracrustal sequence (fig. 2). Further to the east a wide zone of migmatitic and granitic rocks, with remnants of metasedimentary sequences correlated with the

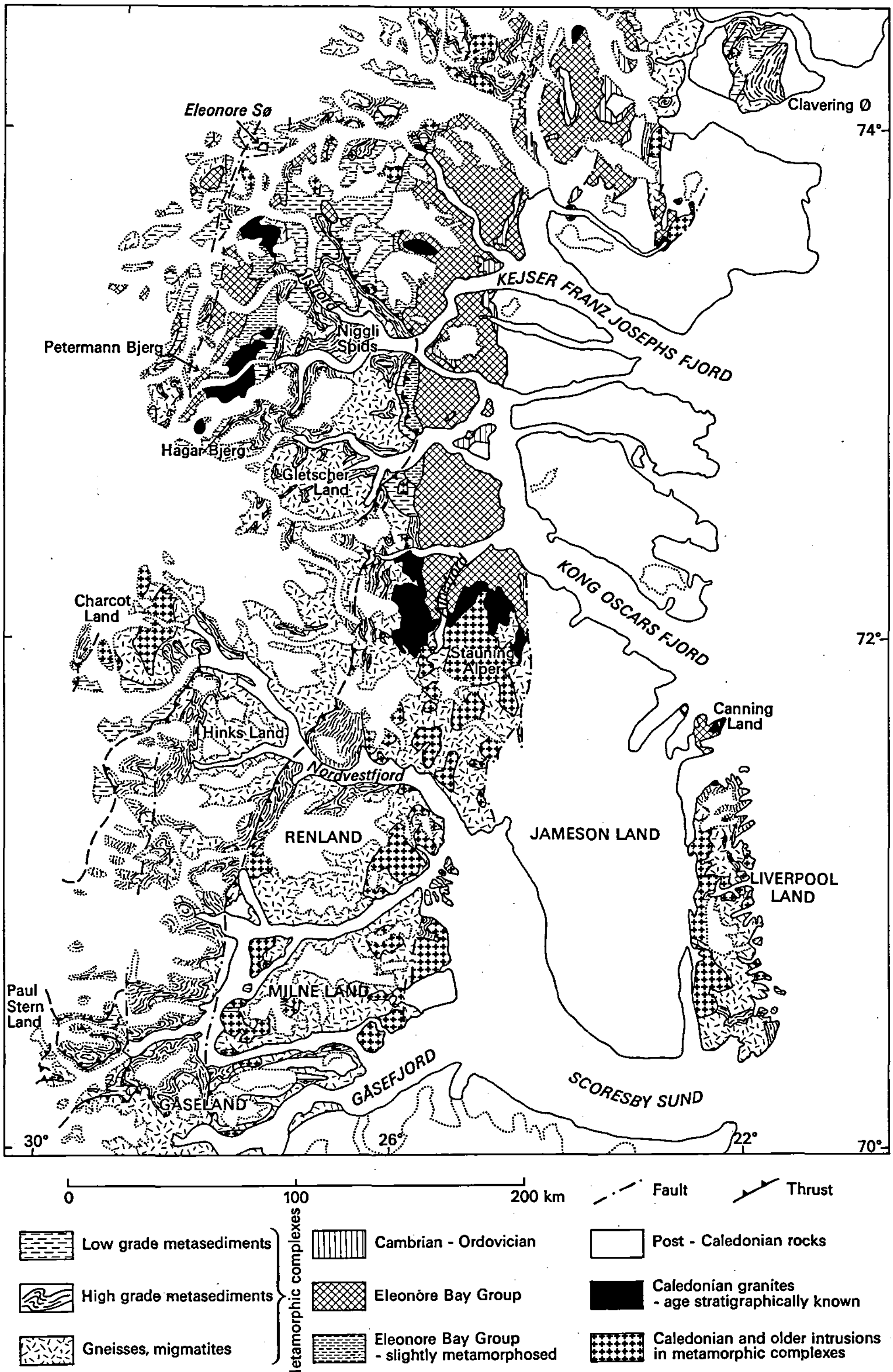

Fig. 1. The Caledonian fold belt between latitudes 70° and 74°N. The Eleonore Bay Group is distinguished from metasediments of uncertain and older age, and Caledonian granites from intrusions of uncertain and pre-Caledonian age.

Krummedal supracrustal sequence, is traceable from Gåsefjord through Milne Land and Renland to the Stauning Alper.

The gneisses, amphibolites and granitic rocks of the Flyverfjord infracrustal complex exhibit complex fold patterns and are cut by discordant amphibolite dykes. Reported ages of 2345 m.y. – 3000 m.y. (Rex & Gledhill 1974; Hansen, Frick & Steiger 1973; Steiger & Henriksen 1972) indicate a history extending well back into the Archean. They form a basement to the overlying Krummedal supracrustal sequence which comprises a varied succession of pelitic and psammitic rocks up to 2500 m thick: kyanite-garnet-mica schists are dominant in southern areas and well banded sequences of mica schist and quartzite are conspicuous in northern areas (Higgins 1974). The supracrustal rocks are intensely folded together with the leucocratic basement gneisses in southern parts of the zone (Phillips, Stillman, Friderichsen & Jemelin 1973).

Rb-Sr analyses

Rb-Sr analyses on 15 samples of kyanite-garnet-mica schists, kyanite-mica schists, calcareous mica schists and micaceous quartzites (table 1 and figs 3 and 4) were carried out on a Varian MAT Tandem mass spectrometer using standard techniques described by Gebauer & Grünenfelder (1974). Rb-Sr ages were calculated using the ^{87}Rb decay constant of $1.39 \times 10^{-11} y^{-1}$. Regression analyses were performed by the least squares method of York (1966). All errors quoted in this paper are 2 σ.

The samples derive from a variety of levels in the Krummedal supracrustal sequence, all in the western part of the Scoresby Sund region (fig. 2). The results from southern, central and northern areas are considered separately.

a) Southern area

Pairs of samples were collected from each of three localities and a further large sample was taken from a fourth locality (fig. 2). Although the sample localities cover a large area, a best-fit isochron through all seven sample points gives an age of 1146±93 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.716±0.005 (fig. 3). Krogh & Davis (1973) have shown that large-scale rehomogenization of

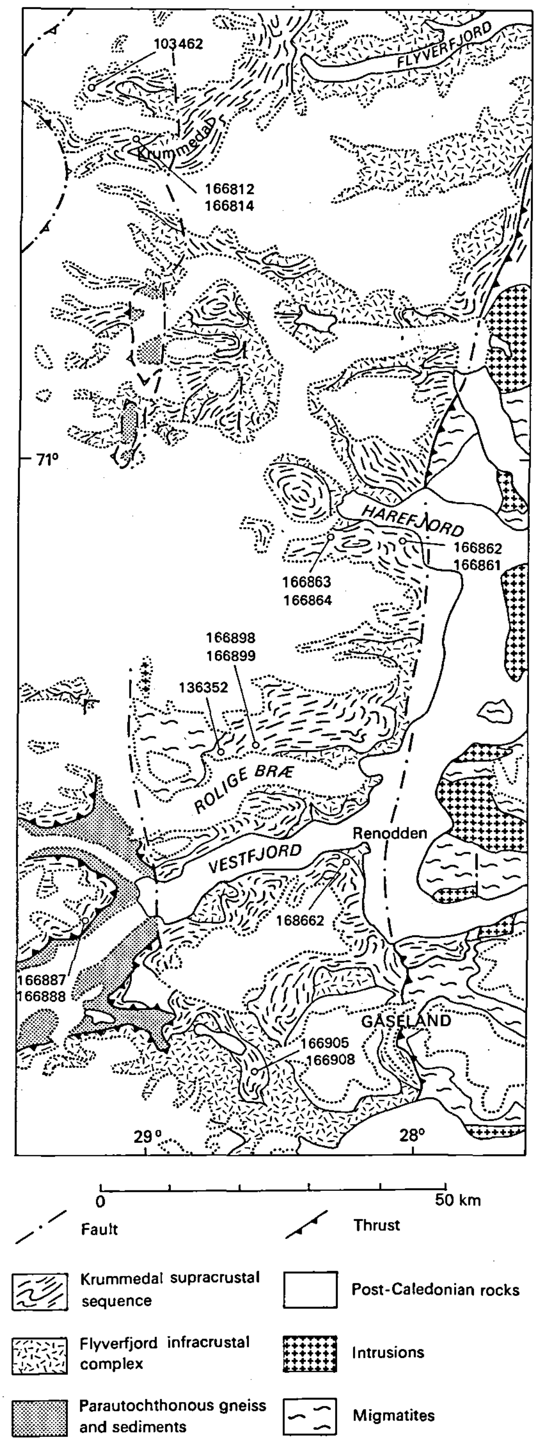

Fig. 2. The inner part of the Scoresby Sund region, showing the locations of the samples used in this study.

Table 1. Rb–Sr analytical data.

Sample GGU No.	Symbol in Fig. 3	Type of sample[a)]	Rb ppm	Total Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Rb/^{86}Sr$ [b)]	*Age in m.y.* [c)]	[d)]
Northern area								
103462		WR	114	234	1.41	0.7336		
166812		WR	55.7	199	0.810	0.7303	448±7	(439)
166814		WR	183	91.4	5.77	0.7610		
Central area								
166861		WR	159	117	3.95	0.7659	900±65	(880)
166862		WR	78.9	254	0.90	0.7275		
166863		WR	169	54.0	9.19	0.8468	955±45	(935)
166864		WR	125	190	1.91	0.7496		
Southern area								
166887	C	WR	153	120	3.71	0.7759		
166888	C'	WR	156	98.9	4.61	0.7864		
166898	A	WR	148	152	2.84	0.7609		
166899	A'	WR	155	144	3.13	0.7660	1146±93	(1122)
166905	B	WR	153	127	3.52	0.7736		
166908	B'	WR	175	137	3.71	0.7782		
168662	D	WR	158	116	3.97	0.7815		
168662		PL	0.537	699	0.002	0.7548	480±10	(470)
168662		Mu	261	65.6	11.7	0.8331		
168662		Bi[e)]	477	4.23	404	3.156	426±10	(417)
136352		Bi[f)]	517	7.02	243	2.216	442±15	(433)

a) WR : whole rock, PL : plagioclase, Bi : biotite, Mu : muscovite.
b) $^{87}Sr/^{86}Sr$ normalized to $^{86}Sr/^{88}Sr = 0.1194$.
c) Estimated errors (2 σ) based on replicate analyses are $^{87}Rb/^{86}Sr = 2\%$, $^{87}Sr/^{86}Sr = 0.1\%$.
d) Ages given in parentheses are calculated using the ^{87}Rb decay constant of $1.42 \times 10^{-11} y^{-1}$.
e) Bi-age based on Bi-whole rock tie-line.
f) Bi-age calculated with an initial $^{87}Sr/^{86}Sr$ ratio of 0.708.

Sr isotopes does not occur by long distance movement and mixing of Sr isotopes even under conditions of high amphibolite facies metamorphism. However, if such heterogeneous schists yield a concordant Rb-Sr whole rock isochron, it seems possible that some process of isotopic reequilibration took place at the time of metamorphism.

A model proposed by Roddick & Compston (1977) may explain such apparent rehomogenization. Before 1150 m.y. the Krummedal supracrustal sequence was obviously inhomogeneous on a small scale. Within a single outcrop considerable variations in petrography and presumably also in Rb-Sr geochemistry existed. In consequence, great variations in $^{87}Sr/^{86}Sr$ values would have developed. However, on a larger scale (several kilometers) the sequence was probably more homogeneous, so that local variations in chemistry would not be apparent. During the 1150 m.y. metamorphism, rehomogenization of the isotopes of Sr need only have occurred on small (outcrop) scale in order to restore near-complete homogeneity of Sr isotopic composition throughout the southern part of the Krummedal supracrustal sequence.

For the sample from Renodden, Rb-Sr analyses of three minerals (biotite, muscovite and plagioclase) were made in addition to the whole rock analyses. The age derived from the plagioclase, whole rock, muscovite isochron gives 480±10 m.y., somewhat higher than the biotite-whole rock line of 426±10 m.y. (fig. 4). Recalculation of the biotite age using the initial ratio deduced from the whole rock isochron (0.716), as suggested by Satir (1975), raises it only slightly to 433 m.y.

Analyses of a further sample from the Rolige Brae area (136352) contributed by Laurent Jemelin (Lausanne) yielded a biotite age of 442±15 m.y. (table 1).

Previously published mineral ages from the same general area include K–Ar ages of 406±10 m.y. (muscovite) and 616±15 m.y. (biotite) on a

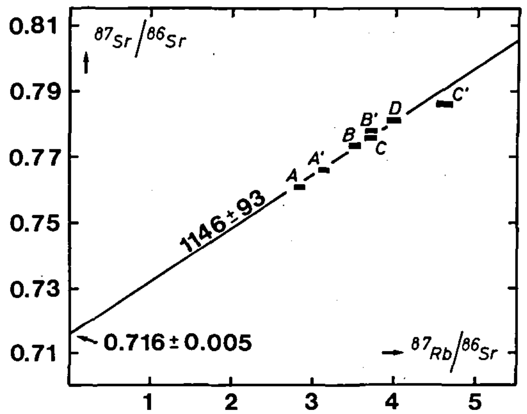

Fig. 3. Rb-Sr whole rock isochron diagram for the Krummedal supracrustal sequence (southern area). See table 1 for analytical data.

kyanite-garnet-mica schist (Larsen 1969), and a K–Ar age on a gabbroic body of 452±16 m.y. (O. Larsen quoted in Phillips et al. 1973).

The most plausible interpretation of the whole rock best-fit isochron age of 1146±93 m.y. is that it represents an early metamorphism of the Krummedal supracrustal sequence.

The incomplete isotopic homogenization among minerals of a single rock sample such as that from Renodden may be the product of different processes. The lower apparent age of the biotite in this case might be regarded as a cooling age, implying that the decrease in temperature from about 500° to 300°C lasted more than at least 25 m.y. The different ages might also be considered to date different events, for example a very low grade event that only affected the biotite system. The (mainly mineral) ages now available between 400 m.y. and 500 m.y. can also be viewed as a near complete adjustment to a Caledonian metamorphism which, however, did not materially affect the Rb-Sr whole rock system in this southern area.

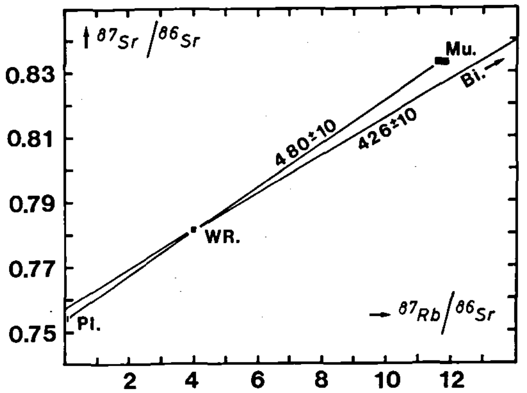

Fig. 4. Rb-Sr mineral isochron diagram for sample 168662 (Renodden).

b) Central area

Rb-Sr whole rock analyses were carried out on pairs of samples from two localities in the Harefjord area (table 1). The four samples of kyanite-garnet-mica schists do not form a homogeneous collection. The respective tie lines of the pairs of samples correspond to ages of 900 m.y. and 955 m.y., but it is doubtful that these represent a geological event. The rocks may have been open systems with respect to Rb-Sr during Caledonian metamorphism, which was not sufficiently intense for complete isotopic homogenization of the whole rock systems.

c) Northern area

Whole rock analyses of three samples of quartzitic schists and calcareous schists from the Krummedal area (table 1) plot on a line corresponding to an age of 448±7 m.y. This age seems to reflect the influence of the established Caledonian event in this area and therefore this isochron, though based only on three points, is interpreted as the time of a complete resetting of the Rb-Sr whole rock system in response to Caledonian metamorphism.

Interpretation of the Rb-Sr analyses and their reliability would have been much improved if larger suites of samples had been available. Sampling was undertaken during the last season of a regional mapping programme, and there has been no opportunity to undertake supplementary sampling.

U-Pb analyses

In an attempt to investigate further the nature of the early metamorphism of the Krummedal supracrustal sequence, monazites and zircons from the Renodden sample (168662) were analysed for U-Pb isotopes using the method developed by Krogh (1973). Lead was measured on a Re single filament by means of the technique of Cameron, Smith & Walker (1969), and uranium runs were

Table 2. U–Pb analytical data.

Sample GGU No.	Symbol in fig. 5	Mineral	mg sample analyzed	Sieve fraction µm	U ppm	Pb rad. ppm	Moles × 10^{-9}/g sample[a)] ^{238}U	^{206}Pb
168662	D	Zircon	13.2	<42	787	91.8	3283	400
168662	E	Zircon	12.2	53–75	780	99.0	3255	418
168662	F	Zircon	10.3	75–125	738	112	3080	457
168662	C	Monazite	3.3	<34	5020	1278	20941	2012
168662	B	Monazite	3.2	<53	5360	1378	22357	2181
168662	A	Monazite	2.7	>150	7005	1177	29221	2096
168662		Monazite rim		>150				
168662		Monazite core		>150				

Sample GGU No.	Symbol in fig. 5	Observed atomic ratios corrected for mass fractionation[b)] $^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	Atomic ratios corrected for common Pb $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
168662	D	6631	0.08012	0.04053	0.12189	1.3092	0.07800
168662	E	3403	0.09829	0.06308	0.12832	1.6648	0.09422
168662	F	4040	0.11880	0.08806	0.14855	2.3617	0.11545
168662	C	7932	0.06549	2.0013	0.09610	0.8444	0.06372
168662	B	5469	0.06645	1.9835	0.09758	0.8595	0.06387
168662	A	6902	0.05900	1.6541	0.07175	0.5633	0.05694
168662		7587	0.05878	1.6595			0.05690
168662		8102	0.05977	1.6299			0.05802

a) Data corrected for blank mass fractionation and common Pb.
b) A correction factor of 1.0011 per mass unit was applied to the observed ratios.

made on a Re double filament following the technique of Shields (1966).

The technique used for the U-Pb analyses of the monazite was modified after that of Hänny, Grauert & Soptrajanova (1975). U-Pb ages were calculated using the following decay constants: $^{238}U=1.53 \times 10^{-10}y^{-1}$, $^{235}U=9.72 \times 10^{-10}y^{-1}$, $^{238}U/^{235}U$ ratio 137.7 (Senftle, Stieff, Cuttitta & Kuroda 1957).

a) Monazites from Renodden

Analyses of three monazite fractions (table 2) plotted on a concordia diagram define a discordia with an upper intersection of 1010±10 m.y. and a lower at 418±5 m.y. (fig. 5).

Previous investigations of monazites from polymetamorphic rocks, for example those of Köppel & Grünenfelder (1975) on gneisses from the Alps, suggest that they normally give concordant U-Pb ages referring to the youngest event. In the case of the discordant data from Renodden, it seems probable that the younger metamorphic event was not sufficiently strong to completely reset the U-Pb system, a conclusion in accord with the evidence from the Rb-Sr mineral systems.

A few of the coarsest grains (those which were most discordant) were leached and rims and cores were separately analysed for their $^{207}Pb/^{206}Pb$ ratios. The rims were shown to contain the "younger" lead (table 2), but neither microscopic nor microprobe examination showed clear evidence of growth stages, except for a tendency for successively larger grains to contain an increasingly larger number of inclusions.

The U-Pb monazite pattern supports the two stage history indicated by the Rb-Sr whole rock and mineral data. The upper concordia intersection may relate to an event at 1100 m.y. and the lower intersection is clearly in accord with a Caledonian disturbance.

b) Zircons from Renodden

Analyses of three size fractions of zircons (table 2) show a discordant pattern (fig. 5), the U concentration and discordancy increasing with decreasing grain size. The discordia intersects at about 700 m.y. and 3260 m.y.

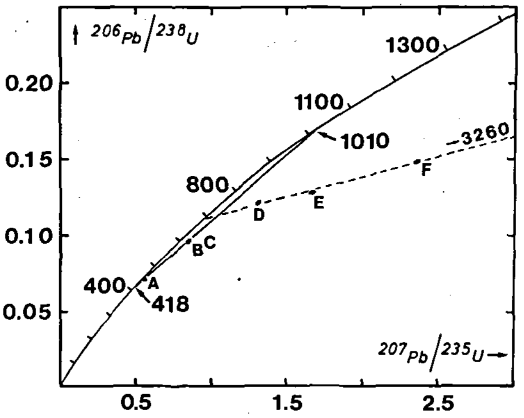

Fig. 5. U-Pb concordia diagram for monazites and zircons from sample 168662 (Renodden). See table 2 for analytical data. If the U-decay constants of Jaffey, Flynn, Glendenin, Bentley & Essling (1971) are used the following intercepts are obtained. Monazites: 420±2 and 982±5 m.y.; zircons: 687±15 and 3197±175 m.y.

Zircons of all three fractions display multiple growth stages under the microscope. Rounded inclusion-rich cores show overgrowths with a tendency to develop pyramid faces, but even the smallest grains do not have euhedral shapes.

The data points do not define an ideal chord. Similar patterns have been observed by Grauert, Hänny & Soptrajanova (1974), who demonstrate that extrapolation of curved patterns may yield erroneous results.

The $^{207}Pb/^{206}Pb$ ratios of the zircons point to a primary age of crystallization of at least 1900 m.y., and it may be deduced that at least the cores of the zircons represent detrital grains derived from source areas of similar or greater age. A possible source area may be the Flyverfjord infracrustal complex which has yielded ages of 2345–3000 m.y. (see above).

Discussion and conclusions

The data presented here permit the following inferences:

(a) The Krummedal supracrustal sediments were derived from one or more source areas at least 1900 m.y. old, as indicated by U-Pb and morphological data from separated zircons.

(b) Rb-Sr data and U-Pb data on monazites suggest a major metamorphism at about 1100 m.y.

(c) Rb-Sr mineral ages indicate an almost complete readjustment during the Caledonian metamorphism.

Based on the Rb-Sr and U-Pb analyses, the Krummedal supracrustal sequence can now be considered most likely to have been deposited in the early Proterozoic, although like other metasedimentary rocks associated with the metamorphic complexes it was formerly assumed to be equivalent to the late Precambrian Eleonore Bay Group. Metasedimentary sequences surrounding the infracrustal units between latitudes 72°–74°N have a lithology, weathering colour and deformation pattern comparable to that seen in the Krummedal supracrustal sequence of the Scoresby Sund region. Similar supracrustal sequences are described from other parts of the East Greenland Caledonides farther north. It is suggested that representatives of an important phase of early Proterozoic deposition are widely preserved within the present East Greenland Caledonian fold belt.

An early major metamorphic event at 1100 m.y. is recorded in the southern areas of the Krummedal supracrustal sequence, and isotopic work on plutonic rocks in other parts of the Scoresby Sund region points to orogenic activity at about the same period; a suite of augen granites associated with migmatite generation and deformation which has already yielded zircon ages in the range of 950 m.y. (Hansen, Oberli & Steiger 1974) has recently yielded a Rb-Sr whole rock isochron of 1005±55 m.y. (Steiger, personal communication 1976). Thus there is evidence for a significant orogenic episode in the Scoresby Sund region corresponding to the Grenville-Sveco-Norwegian event of North America and Northern Europe (900–1200 m.y.).

Demonstrable outcrops of the Eleonore Bay Group between latitudes 70°–74°N in East Greenland are now restricted to non-metamorphic or slightly metamorphosed sequences in a broad zone east of the metamorphic complexes and a narrower strip in the nunatak zone. This viewpoint (expressed in fig. 1) may be over-restrictive, but pending the results of new isotopic studies the age of the widespread supracrustal successions associated with the metamorphic complexes is an open question.

The isotopic studies carried out in the Scoresby Sund region reported here, and those published elsewhere, have necessitated reinterpretation of many aspects of the genesis of the East Greenland Caledonides. They form the basis for the new regional description presented by Henriksen & Higgins (1976), and also the speculative interpretations of Higgins (1976).

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Dansk sammendrag

Rb-Sr dateringer af metamorfe sedimenter fra Krummedal serien i Scoresby Sundområdet viser, at hovedmetamorfosen formodentlig er ca. 1100 millioner år gammel. En senere kaledonisk overprægning af serien genspejles i mineralaldrene. Denne udvikling kommer også til udtryk i U-Pb systematikken i monazit, der ligeledes peger mod to metamorfe episoder, en hovedmetamorfose omkring 1000–1100 millioner år og en senere overprægning i kaledonisk tid. U-Pb undersøgelser af zircon tillader ikke nogen konklusion vedrørende metamorfe episoder, men viser, at sedimenterne oprindeligt stammer fra bjergarter, der er mindst 1900 millioner år gamle.

De foreliggende dateringer og isotopsystematiske undersøgelser giver god grund til at antage at Krummedal serien er blevet aflejret i tidlig Proterozoisk tid. Dette er i modstrid med tidligere betragtninger, ifølge hvilke de metasedimentære serier alle er blevet korreleret med den senprækambriske Eleonore Bay Gruppe. På grundlag af den store lighed (såvel lithologisk som tektonisk) mellem Krummedal serien og de metasedimentære serier i de nordforliggende områder er det nærliggende at antage, at der i det østgrønlandske foldebælte findes langt større mængder af tidlig Proterozoiske aflejringer end tidligere formodet.

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